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THE LONG ROAD TO IMPROVEMENT IN MODELLING AND MANAGING ENGINEERING DESIGN PROCESSES

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Abstract

Managing complex engineering design processes is a challenge for industry, which is looking to academia to provide tools and methods to support them.

The Modelling and Managing of Engineering Processes Special Interest Group of the Design Society aims to support industry in understanding, modelling and running design processes by bringing together a community of design researchers and interacting with industry by identifying research challenges and working together to resolve them.

This paper maps out research challenges for MMEP and reflects over some of the challenges we have as a research community in meeting these ambitious goals.

This paper begins by presenting an ambitious research roadmap developed in 2008 and then compares the roadmap with the research topics that current members of the MMEP SIG are working on before reflecting on how and where we have made progress and what would be serious progress in this area.

Based on the analyses of research topics and progress, the paper concludes with a discussion of the evolution of research topics and associated challenges for design research, and sketches measures required for improving our efficacy as a research community.

Keywords: Process modelling, research roadmap, Design management

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1 INTRODUCTION

Over the last decades engineering design research has led to systematic tools and methods that support industry developing competitive products. These tools and methods have been included in university teaching of engineering design and shared through engineering design textbooks that have become classics and defined much of the way we now think and talk about engineering design.

However, while unprecedented technical advances have led to more complex and more reliable products than they have been in previous generations, they have also brought increased challenges in the coordination and management of these processes as teams have increased and diversified both in their disciplinary background and in their geographic distribution. It is this continuous change of design practice that stipulates the continuous demand for further investigation and for further improvement or adaptation of developed support (tools, methods and processes).

Engineering processes are central for product development and design. Structured processes are necessary to orchestrate the interplay of people involved, and for ensuring “the correct and timely use of the appropriate approaches & procedures, methods, data, and tools” (Heisig et al. 2009) to assure that products are developed on time and on budget. One important tool in understanding and managing design processes in such a context are process models that provide both an overview of a process and a means to assess progress in the design process (Eckert and Clarkson, 2010).

This paper reports on several attempts to map out research challenges for MMEP, first in 2008 through a series of industry workshops and later through workshops of design research; and reflects over some of the challenges we have as a research community in meeting these ambitious goals.

The Modelling and Managing of Engineering Processes (MMEP) Special Interest Group of the Design Society aims to support industry in understanding, modelling and running design processes by bringing together a community of design researchers and interacting with industry by identifying research challenges in MMEP and working together to resolve them. Strategies, approaches, methods, and tools for modelling of, building up, for optimising of, and for managing dynamically engineering processes are investigated within this SIG (Heisig et al. 2009).

The MMEP SIG was founded in 2000 by Sándor Vajna from the University of Magdeburg. Later, John Clarkson from the Engineering Design Centre in Cambridge joined the SIG as a Co-chair. Both were working on approaches to model design processes. However the tradition of the MMEP SIG goes back to the systematic design methodology tradition of Germany in the 1970s and 1980s.

The outlook of the SIG is to deal with challenges from practice faced throughout entire design processes of complex engineering products. The common theme of the SIG has always been a shared interest in complex design processes rather than a particular modelling approach or theoretical viewpoint. The SIG’s role is being a facilitator for networking, for identifying research needs, for developing research ideas, and for exchanging and discussing research results, by incorporating researchers and practitioners.

Many of the members of the SIG are interested in modelling design processes, either as a means of understanding the processes that they are studying or the complexity of the tasks that they want to see supported. Most of the researchers are working closely together with industry and some industry experts are active members of the special interest group.

This paper begins by presenting an ambitious research roadmap developed in a series of workshops in 2008 and then compares the roadmap with the research topics that current members of the MMEP SIG are working on before reflecting on how and where we have made progress and what would be serious progress in this area.

2 THE MMEP RESEARCH ROADMAP

2.1 Development of the Research Roadmap

The MMEP Research Roadmap was created as a collaborative effort of the Engineering Design Centre (EDC) at the University of Cambridge, the chair of Integrated Product Development, School of Industrial Engineering and Management at the Royal Institute of Technology (KTH) Stockholm, Sweden and the Institute of Product Development at Technische Universität München (TUM), Germany. The three academic institutions organised a series of three industry workshops with a total of 39 practitioners from 27 companies.

The intention of these workshops was to identify challenges and future needs of different industries in the area of modelling and managing engineering processes.

The workshops were organised into four sessions addressing questions covering the following topics:

- *understanding modelling processes* (i.e. individual understanding, kinds of models, use and usefulness of models),
- *managing modelling processes* (i.e. creation, dissemination, implementation, etc. of models, quality, and granularity of models, and impact of human factors on modelling)
- *exploiting modelling processes* (i.e. added value, expectation regarding future developments, potentials for improvement, and risks of modelling), and
- *road mapping* (i.e. what to do next and what are expectations of industrial partners)

The results of these workshops have been presented during a workshop at the International Conference on Engineering Design ICED'09 in Stanford in August 2009. More details about the workshops and the creation of the Roadmap can be found in a MMEP whitepaper (Heisig et al. 2009).

2.2 The resulting research agenda

During the workshops practitioners and academics identified a broad range of research topics as relevant. The topics were structured along a timeline and are grouped into seven columns (see Figure 1) (Heisig et al. 2009):

1. **Theory:** description of current state of practice and research in the area, case studies focussing on identification of best practices
2. **Training:** development of curriculum for teaching process modelling
3. **Tools & Techniques:** improvement of visualisation, grand visions in that area are: visualisation of 3D development processes (providing a “walk through” the process), and automation of models
4. **Metrics & value:** demonstration of benefits and value of process modelling, metrics for monitoring, management and improvement of processes
5. **Application:** All applications of process modelling like analysis, simulation and prediction, real-time dynamic forecasting and process control and automation
6. **Implementation, Human Factors and barriers:** Support for the implementation of process modelling considering human factors and (organisational) barriers, research should be inter- and cross-disciplinary
7. **Standards:** standards that enable global exchange and allow adaptation towards local requirements

The final outcomes of the research process are three grand visions, where the results of different research efforts come together (Heisig et al. 2009).

- **Virtual teams** (with presence)
Support for modelling, visualisation and management of processes, enabling collaboration of virtual teams
- **Automation of Models**
Application of models for analysis and diagnosis, real-time forecast, process control and automation
- **Electronic war room for decision support**
Support for dynamic design process visualisation that offers simulation and forecast functionality for projects and processes, i.e. a combination of virtual teams and automated process models

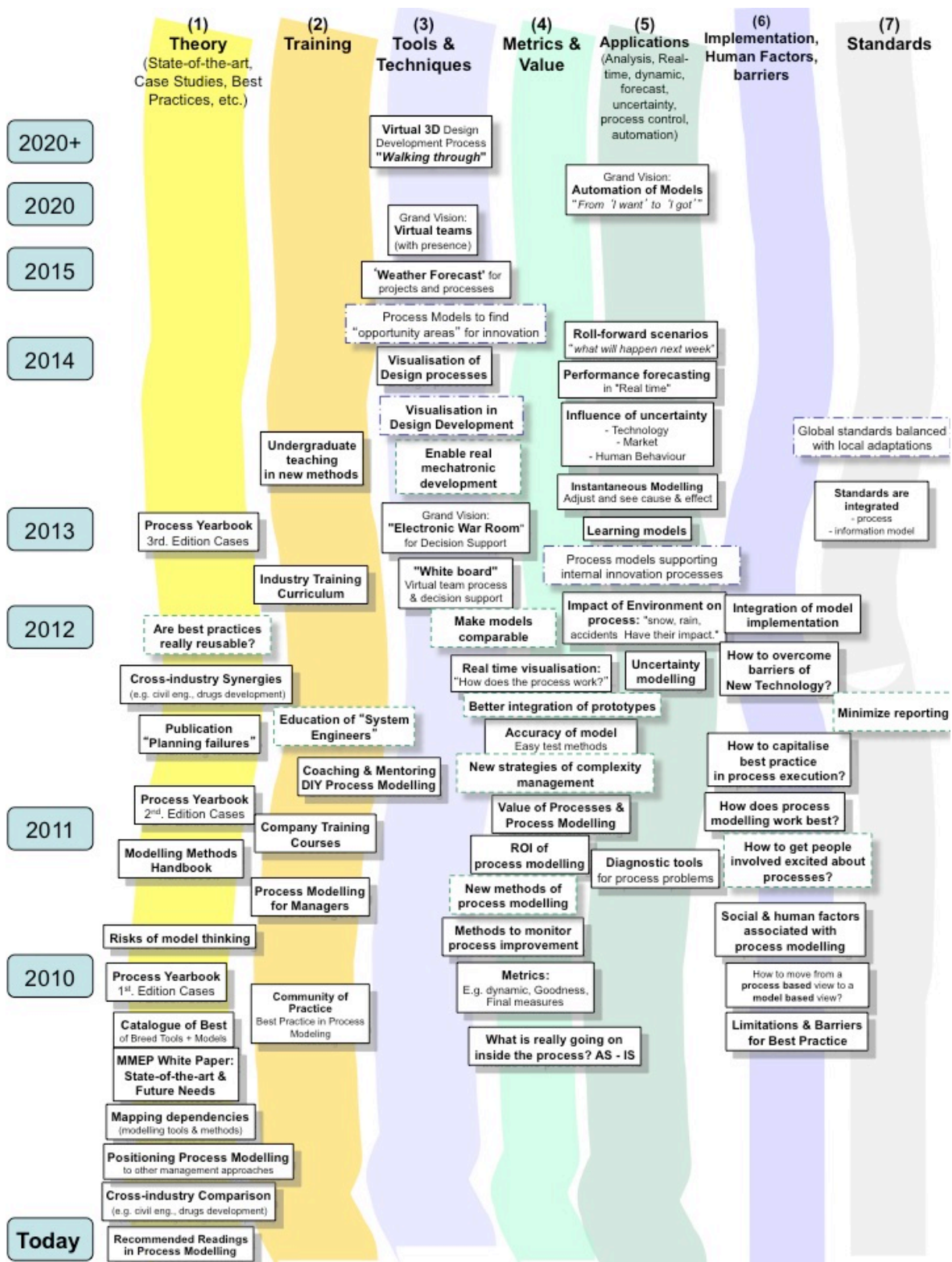


Figure 1. The MMEP research roadmap (Heisig et al. 2009)

3 CURRENT RESEARCH TOPICS IN MMEP

One of the objectives behind developing the research roadmap was to obtain joint funding, which would address these issues, however that never came to be. Instead, the group that developed the research roadmap dispersed and worked on other issues as they obtained funding elsewhere. Instead the research continued in a much more fragmented fashion. When the authors took over as chairs of the special interest group the research landscape was surveyed again through a series of workshops at conferences, smaller workshops and specific MMEP conferences.

3.1 Research topics presented at MMEP conferences

Three specific MMEP conferences took place. The first in 2010 in Cambridge was held immediately before a meeting of the Design Society's SIG on Managing Structural Complexity and capitalised on the overlap in the participants for both special interest groups. The meetings in 2012 in Cambridge and 2013 in Magdeburg were smaller events. Figure 2 shows a list of the topics presented at the first two MMEP conferences following the structure of Heisig et al. (2010), where the topics in italics were presented at the second MMEP conference (Heisig and Clarkson, 2014).

- I. Engineering Process Management in Theory
 - a. Theory and epistemology of process modelling
 - b. Property validation of products
 - c. *Macro-level description design processes*
- II. Managing Complex Engineering Processes
 - a. Situation specific planning processes
 - b. Impact analysis of new design models
 - c. Design process planning – design attainment model
 - d. Effect of uncertainty on the design process
 - e. Effects of iterations in engineering processes
 - f. *Determining parallelisation of design processes*
 - g. *Integration of physical and virtual testing in product development*
 - h. *Managing iterations in design processes*
 - i. *Context-sensitive adaptation of design processes*
- III. Managing Product and Process Information
 - a. Capturing the design process
 - b. Data estimation on complex design processes
 - c. Event graphs for runtime change management
 - d. *Integrated modelling of information to support design processes*
- IV. Engineering Process Management in Practice
 - a. Quality of designs
 - b. Continuous process improvement
 - c. Interactive visualisation of design processes
 - d. Collaborative design environment for design management
 - e. Robust process for integration of innovations
 - f. *Failure mode avoidance in product development*

Figure 2. topics of MMEP conferences

The range of topics shows how issues considered in MMEP are linked to general issues in design processes, such as uncertainty or failure. The breadth of topics was reflected in the third MMEP conferences (Schabacker et al., 2014), which included issues such as risk management or collaborative tools.

3.2 Research topics in MMEP identified during workshop series

A series of workshops was organised in order to review the current research topics in the MMEP community with respect to the topics outlined in the MMEP research roadmap. Six events belong to this series:

- August 2013, Seoul, South Korea, during the International Conference on Engineering Design ICED'13, 15 participants

- September 2013, Cambridge, UK, 22 participants
- December 2013, Milton Keynes, UK, 10 participants
- April 2014, Karlsruhe, Germany, 14 participants
- May 2014, Cavtat, Croatia, during the International DESIGN conference, >35 participants
- June 2014, Cambridge, UK 13 participants

Most of the participants were young researchers. Participants from industry joined three of the workshops. Their contributions were very useful in guiding discussion towards industry relevant topics. While the majority of the participants are from the UK or Germany, researchers from France, Denmark, Luxembourg, US, Brazil, Japan were also represented. Large research groups such as the EDC (Cambridge, UK), IPEK (Karlsruhe, Germany) and TUM (Munich, Germany) are constantly active in the area.

During the workshops the topics of on-going research projects of the participants were captured. These were generally broad topics or projects rather than specific titles of papers. The following top 10 research topics could be identified:

- Process modelling
 - Capturing of design process' rationale
 - Integrated modelling of product and process
 - High-level process modelling
- Managing complex systems and processes
 - Change and flexibility in complex environments
 - Coupling of domain specific design processes
 - Relationship network analysis of information flows
- Knowledge management in the process
 - Organising knowledge about process and product and relevant relationships
 - Using knowledge about past projects for process simulation
- Processes simulation
 - Process simulation data management
 - Dealing with uncertainty in process simulation
- Lean management
 - Value in product development processes
 - Metrics and systematic assessment of process efficiency
- Decision making
 - Considering interdependencies between product and process
- Human factors in the design process
 - Consequences of users involvement on design processes
- Computer based support for design management
 - IT based support of reuse of process knowledge
 - Cloud based support of collaborative design
- Coupling of design and manufacturing
 - Early consideration of constraints from manufacturing process on parts design and design processes
 - Interdependencies between manufacturing processes and design processes
- Product Service Systems design processes
 - Integrated PSS and business model design process

4 PROGRESS SO FAR

4.1 Reflection on achieved progress

Most of the research issues stated in the research roadmap are still as valid as they have been in 2009. Besides the publication of the MMEP white paper itself none of the issues described in the research roadmap would be considered as completed to a degree that no further research would be required.

Rather than working in a disciplined fashion through the research agenda, academic research has addressed many of those issues to a certain extent, so that some progress has been made, but not collected into a single output in the form of a report or a tool that could be handed over to industry.

As design processes are fundamentally affected by both the products that are created with them and the organisations in which they take place (Gericke et al. 2013a, 2013b), there is inevitable a huge variation in the processes and the barriers and enablers for their improvement. In the absence of good theoretical foundations of design research, which would allow accounting for these factors, generalisation from case studies companies or industry sectors remains challenging. Therefore to reach a definitive conclusion on any of these topics it would be necessary to carry out comparative studies or survey a large number of different organisations. For example while many companies have a set of measures to assess the quality of processes or process models, these have not been systematically collated. Which sub-set of measures applies to which company or process therefore remains an open question, even though different publications have talked about measures.

4.2 Reasons for slow progress

Working through such a research agenda requires joint research worldwide, which needs joint funding. Much of the research represented in the MMEP SIG is funded directly by industry or carried out in conjunction with industry, so that the research activity often prioritises delivering results to industry partners without having the time or resources to draw out generally lessons that could be used to advance such a research agenda.

While the roadmap set out a research agenda, it has not been followed up with significant investment in design process research either by the participating companies or the relevant national and international funding bodies. For example in the UK design research received a lot of funding originally as design centres and later as integrated manufacturing centres from the government in the 90s and early 2000s, however now funding has shifted both towards manufacturing and the development of new technologies. Similarly, design process funding has not really been a focus of European Union funding, so that MMEP research had to be integrated with funding for particular industry sectors such as aerospace or transport as part of a larger project. While companies collaborate very regularly with universities through industry projects in the area of MMEP, this research is often result oriented and does not result in significant publications that would build up a scientific body of knowledge for MMEP.

Many of the issues addressed in the research roadmap, would require serious involvement of experts from different fields, such as psychologists and computer scientists, which are difficult to attract to an area, where it is difficult to attract funding from the larger funding bodies. Much of the research also needs access to design processes supplemented with substantial amounts of data. Companies have been generally reluctant to grant that type of access and if they do, the data and information remains confidential and cannot be shared across the research community to work on it jointly.

Another barrier to sustained results in MMEP lies in a lack of continuity of research activities in the area caused by e.g. shifting priorities of research funding agencies, shifting priorities of industry partners, young researchers leaving academia for positions in industry, and a lack of overlap between researchers.

The perception of insufficient progress in this research area by research funding agencies and industrial partners might be another barrier for continuation of research. The perception might be caused by the lack of clear success criteria for achieving results and a mismatch between expectations regarding the speed of progress on the one side and realistic results on the other side. This mismatch is well illustrated by the timeline of the research roadmap (see Figure 1). The continuous evolvement of industrial practice, which requires continuous research on topics, which seem quite similar (but address different realities as practice evolves), also contributes to this perception.

4.3 What would constitute progress

The roadmap laid out a lot of goals without a clear definition of the success criteria for having achieved any of the steps in the road map. There is an implicit assumption that the research will reach a point that the research is at least good enough to be usable or at best becomes an established part of formal processes and procedures. In an ideal there is an ambition to develop industry best practise. However, a result-oriented view makes it difficult to assess progress short of revisiting the participating companies. Even if they could be gathered again, it not would be clear what the relation between the research in the MMEP community and improvements in company would be.

The design research community in general needs to negotiate both amongst ourselves and with industry what would constitute a significant contribution in each of these fields and how the results

would be shared amongst interested researchers. Whether progress is made varies with organisations and products. Validating the results beyond the particular case study that they draw on can be time consuming and difficult. Therefore, it is necessary to clarify what constitutes progress. Would a topic be adequately worked out if for example there is a PhD thesis on the subject, a journal paper or a review paper or would a large-scale research project be required? One way to measure success is by the degree to which tools and methods are adopted in industry. However, as there is time delay between the original research and industry adoption, industrial practice has moved on meaning that many topics need to be revisited.

5 OBSERVATIONS ON RESEARCH GAPS

There is still a substantial interest of industry in the MMEP topics and industry experts welcome the dialogue with the research community. These experts don't have easy access to the insights and tools that the community has generated, as only some of it is disseminated in textbooks or publications targeting at industry.

During the workshop series a couple of specific methodological issues (of current projects) and some general problems with design research were identified together with the participants, which have an effect on the efficacy in progressing according to the research agenda formulated in the MMEP research roadmap as well as on the knowledge transfer between industry and academia.

5.1 Methodological issues

The scope of the applicability of research findings is rarely stated explicitly or described vague as "design" or "design of complex products", so that it can be very difficult to recognise areas where the research applies particularly well. From an industry perspective it would be extremely useful, if research would be repeated in a different industrial setting to corroborate the findings and identify places where the tools and methods can be adapted. However, this type of research can be difficult to publish, as engineering design research unlike other sciences does not have a research culture of repeating research to validate it.

In particular the research workshops show a number of systematic shortcomings across many of the research projects presented:

- Unrealistically high ambitions of what can be achieved in course of a PhD or a even a bigger research project;
- Unconnected work across different research groups often hindered by the use of slightly different vocabulary;
- Little awareness of the overlap in the work of different research groups;
- Different case study companies or industry sectors can be barrier to knowledge transfer;
- Little awareness of previous research on the same topics, as much of the research has not been published;
- No critical mass to advance the research systematically.

There are however pockets of integrated and prolonged research effort for example around engineering change management, process iteration or process optimisation.

5.2 General problems with design research

In academia we have problems with understanding the real complexity of industry processes and the product complexity. In industry some of the challenge is about making use of the research findings. The bi-lateral transfer of knowledge between academia and practice is a fundamental challenge (Wallace 2011). An important question for the research community is how we can make our research more actionable.

A challenge for the communication with industry lies in the management of expectations, especially regarding speed (i.e. how fast can specific results are achieved) and benefit (i.e. to explain how our research can contribute in a measurable form to their business).

As a community we have to reflect on both. Questions, which should be discussed, are:

- Why have we not achieved what industry asked for? What are additional explanations?
- Do we truly understand the complexity of the challenges that are mentioned in the MMEP research roadmap?

- If funding is not available: Should we question our research visions? Are the benefits of our research evident?
- Are structure and distribution of research efforts suited to the research challenges?

5.3 Evolution of research topics

MMEP stands for Modelling of Engineering Processes and Managing of Engineering Processes. Currently we have a broader field emerging of people who are attracted to MMEP events, this might be a result of the format of the workshops we are running or a genuine change in the focus of the research topic.

We have essentially three groups of people coming together:

- Modelling of engineering processes and using these models to manage and direct processes. There are many open questions about how to model, what a model is, how to build it, how to get a company to make use of a model, and how to establish a model. There is also quite an interest in process simulations.
- Managing engineering processes, this is partly concerned with information flow or softer areas, lean management, risk management, project management, transfer of agile approaches, etc.
- Modelling different aspects of engineering products and the implications on managing the process. Essentially we seem to have three related areas emerging: engineering change and change prediction, platform architecture and functional modelling. There is also a growing awareness that this depends on the state in the design process and that we need to understand what we want to do with the information once we have it.

Some people combine this explicitly to look at the relationship between products and processes, e.g. link of process models to PLM, DMM of process tasks and product components.

Like in other areas of design research the research scope of MMEP would benefit from better theoretical foundation of design research and collaboration with other research fields on the focus areas of MMEP. There are a number of the fundamental questions in that the MMEP community as well the wider research community, which need to be addressed:

- Models and modelling: Models: What are models? How are models built? How is the model affected by modelling approach and purpose?
- Learning across case studies: How do processes differ for different organisations and products? How can we generalise from case studies?
- Relationship between the product and its design process: How does the product affect the design process and vice versa? How do tools and methods need to be adapted to reflect this? How can we integrate models across products, design processes, user models, manufacturing processes etc.

Some of these fundamental questions will require both theory development and further case studies as well as the willingness to look beyond the specific problem of the research to its wider complications.

6 CONCLUSIONS

As a research group we can address some of the immediate steps in terms of improving the value of our research for the community. We can address benchmarking problems, where a number of groups look at the same problem to compare across different approaches to step back from the situatedness of the case study research. As much of the research is not well connected to other current or past research, we can work on review papers that bring together different streams of research and provide a starting point for other researchers.

However, this only addresses some of the issues. As this is applied research, industry needs to support our community by giving us access to data to conduct research and be willing to wait for results, otherwise MMEP research drifts into consultancy and the results have little validity beyond the specific case study.

To make significant progress it would be necessary for different groups of researchers to work together in a more integrated and coordinated way, which would require sustained funding for MMEP topics across Europe and the rest of the world either from industry or public funding bodies. While national and European funding for MMEP topics has been available, this was often in the form of subsidiary research in technological or IT projects. As a community we will need to lobby both industry and funders to bring MMEP to the forefront as enablers of innovation.

We need to learn from other fields and have a greater dialogue across fields: computing, complexity, operations research, management science, system engineering.

As it is a long road to achieve grand visions, we should better go it together.

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